Advances in Technology of Asphalt Paving Materials Containing Used Tire Rubber

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The blending of crumb rubber with asphalt cement has been in practice for years and a number of manufacturing processes have been developed in Europe as well as in the United States. However, all these processes have a major drawback: the asphalt rubber binder must be used within a few hours after being manufactured. In 1987, Beugnet, a road contractor in France, designed a new rubberized asphalt formula. This new formula improved rheological properties of the asphalt rubber binder, including increasing the shelf life of the binder for up to 8 days. Therefore, this new asphalt rubber binder could be used just like conventional asphalts or polymer-modified asphalts. The dry system of rubber-modified asphalt concrete has historically been limited to only a patented process. Major drawbacks of this system include the addition of crumb rubber to a unique "gap-graded" aggregate gradation, and nonconventional design criteria. These factors contribute to the high cost of using the material when compared with conventional asphalt concrete. The dry system of rubber-modified asphalt concrete has also experienced a major advance. A rubber-modified asphalt concrete system has been developed by H. Barry Takallou. This system relates to a process for producing an asphalt concrete composition made up of coarse crumb rubber and fine crumb rubber incorporated into a standard dense-graded aggregate mixture. This process is characterized by the various constituents of the asphaltic binder and fine crumb rubber, mixed intimately by a physical reaction. This will result in a higher viscosity binder in which the optimum reaction is achieved when the fine crumb rubber particles reach optimum swelling. A pre-reaction or pre-treatment of crumb rubber with a catalyst may be needed to achieve the optimum crumb rubber particle swelling. This system can be designed using conventional testing procedures and complies with conventional design criteria. The use of this system is in the public domain.

Research to improve and enhance the performance of asphalt concrete by the addition of natural and synthetic rubber to an asphalt concrete binder has continued worldwide for more than a century (*1*). Historically, the objective of the research of the addition of rubber—natural, synthetic, and combinations of both—to asphalt binder, was to develop a mixture to improve the physical characteristics of asphalt concrete by improving elasticity. Results of several demonstration projects using rubberized asphalt indicate increased fatigue resistance, retardation of reflective cracking, improved skid resistance, and increased durability (*2*). However, current interest in rubberized asphalt has been heightened by its potential as a recycling option for used tires.

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The addition of crumb rubber to an asphalt cement binder was successfully accomplished in the United States in the early 1960s (*1*). This process of heating and reacting crumb rubber with asphalt cement has continued to be developed and used since those early applications. Success of initial patching placements using the rubberized asphalt led to its use as a "stress-absorbing membrane" (SAM) in the late 1960s. Continued research and development led by 1972 to the development of a stress-absorbing membrane interlayer (SAMI). By 1975, the next milestone in the development of the rubberized binder was to be seen in its use in an open-graded friction course (*1*).

In these processes, crumb rubber was added to the asphalt binder, heated and interacted, to form a rubberized binder. In an effort to standardize a description of the rubber asphalt technologies, this process is now widely referred to as the wet system.

A different asphalt rubber technology was also developed in the early 1960s in Europe. It was first used in the United States in a late 1970s demonstration project in Alaska. In this process, the design required a unique mineral aggregate gradation. This unique gradation was required to allow a gap in the aggregate gradation curve. This gap, in the range of 1/4 in. to sieve size No. 10, was to be filled by the addition of coarse crumb rubber. The majority of the crumb rubber is larger than sieve size No. 10. The addition of the crumb rubber is either at the pugmill with the hot aggregate before the addition of the asphalt cement, or at the recycle fit opening in a continuous, or drum drier operation. The crumb rubber is added as a separate constituent to the mixture, and therefore referred to as the dry system.

Both wet and dry systems have been used in demonstration projects throughout the world. The systems have continued to increase in use with each passing year. The engineering community has recognized an improved performance when using crumb rubber in asphalt concrete mixtures. Also, the addition of crumb rubber from whole tire recycling is a recycling option to the used tire disposal problem.

Each year in the United States, approximately 240,000,000 used tires need disposal. Landfills are reluctant to accept used tires for disposal because they resist compaction, take up a disproportionate amount of space, and may also become buoyant, penetrating the covering membrane of the landfill (*3*). Through state and local action, many landfills across the United States no longer accept used tires. This lack of a practical or efficient means of used tire disposal has led to the nationwide practice of used tire stockpiling. In the early 1980s, recognition of the dangers associated with used tire stockpiling came the public's attention. Used tire stockpiles were an excellent breeding ground for mosquitoes, ideal habitat for vermin and, as evidenced too often, a potential fire hazard, capable of great environmental damage.

The need for used tire disposal and recycling options capable of eliminating large quantities of waste tires is needed. One solution to the used tire problem is the widespread use of asphalt concrete containing crumb rubber from whole tire recycling. Currently, there are major barriers to widespread use of asphalt rubber. However, the technological advances in both the wet and dry systems described in this paper can reduce those technological barriers.

Passage of the Intermodal Surface Transportation Efficiency Act of 1991 contained a section directing the use of recycled paving materials. This act requires that states use crumb rubber from whole tire recycling in 5 percent of their asphalt concrete usage beginning in 1994. This usage increased by 5 percent/yr to a maximum use of 20 percent in 1997. Mandated use of crumb rubber in asphalt concrete is required by Congress as a means to alleviate the used tire problem by establishing a market for crumb rubber produced from whole tire recycling.

MAJOR BARRIERS TO WIDESPREAD USE OF RUBBER ASPHALT

There are several barriers to the widespread use of both the wet and dry systems of asphalt rubber, including use of specialized equipment, unique aggregate gradations, specialized mix designs, lack of standard design criteria, cost of crumb rubber, and use of patented processes. In both the wet and dry systems these combined barriers result in the major barrier to the use of asphalt rubber: the high cost of asphalt rubber when compared with the cost of using conventional asphalt concrete.

Although high cost is a barrier to both systems, the factors causing the increase are different in both.

In the wet system the increases in cost are attributable to the following factors:

- Rubberized binder must be used within hours of its production; therefore the high cost of mobilizing the specialized equipment (blending unit, metering unit, storage tanks, etc.) at the production facility must be recovered in the cost per ton of rubberized binder used on that project.
- License fee for using the patented process.

In the dry system the increases in cost are attributable to the following factors:

- Unique aggregate gradation,
- Introduction of crumb rubber to asphalt plants,
- Higher asphalt and filler content design requirements, and
- License fee for using the patented process.

The following sections describe advances in technology that address the barriers to widespread use of asphalt rubber.

Advances in Technology of Rubber Asphalt Binder (Wet System)

The incorporation of crumb rubber into an asphalt cement binder has been researched in Europe since the 1960s. In France, the incorporation and reaction of crumb rubber particles of particular sizes into the an asphalt matrix was initiated in 1981 by Beugnet Company. In this process, finely ground crumb rubber is mixed directly with asphalt cement at an elevated temperature (200°C) by means of an oil extender. The proportions of crumb rubber varied from 10 to 30 percent and of the oil extender from 3 to 15 percent by total weight of the binder. This rubberized asphalt binder is marketed under the trade name Flexochape.

The reaction of the rubber with the asphalt binder, creating an asphalt rubber binder, displayed several improved properties:

- High viscosity (8 poises at 200°C),
- Ball and ring softening point greater than 60°C,
- High elasticity and high resilience at low temperatures, and
- Cohesiveness 10 times greater than for asphalt alone at 20°C.

In 1985 it was discovered that the reaction processes could be improved by incorporating a catalyst into the mix. The improvements on the original binder were

- Greater viscosity stability (i.e., better ductility for field use);
- Increase in the softening point temperature (as much as 15 to 20 percent depending on the amount of catalyst). This suggests that the binder remains less sensitive to temperature;
- Longer preservation of the original elastic properties of the binder; and
- Better adhesion.

Production Barriers

Even with the improved properties achieved by adding crumb rubber to asphalt cement binder at evaluated temperatures with a catalyst, the contractor faced the same problems in France that were seen in the United States. A major disadvantage of the use of the rubberized asphalt binder was that it had to be used within hours of production. Mobile units were employed to produce the asphalt rubber mixture at the project production site. All costs associated with the transportation, setup, and removal of the mobile equipment had to be recovered in the unit cost of the tonnage produced.

Technical Barriers

Technical questions remained on the quality and consistency of the binder produced because the product is the reaction of several constituents. As in any chemical reaction, the kinetics are determined by reaction temperature and reactant proportions; these also affect storage time.

Viscosity testing shows that the viscosity of asphalt rubber binder at a digestion temperature of 200°C reaches its peak after 45 min; then remains constant for 1 or 2 hr. Afterwards, viscosity declines steadily and the quality of the binder is diminished, as demonstrated in Figure 1.

Softening Point Temperature follows the viscosity curve, falling after a certain reaction time, indicating that the binder is degrading. Therefore, it must be recognized that there are certain practical considerations in the production of asphalt rubber binder: (a) the binder must be mixed on-site and (b) the binder must be used no later than 6 hr after mixing.

As a result, production of an asphalt rubber concrete mixture is limited to the amount of asphalt rubber binder that can be produced by the mobile equipment at the asphalt plant site. It seemed obvious that a major technological barrier to the widespread use of asphalt rubber binder is faced without the product being storable. Therefore, a major study was undertaken in France in 1987 to formulate an asphalt rubber binder that could be stored in vats for several days after mixing without appreciable changes in viscosity or other properties. The asphalt rubber binder could thus be produced in central terminal locations and shipped to different asphalt paving production plant locations, similar to conventional asphalt binder.

Evaluation of Storable Asphalt Rubber Binder

A laboratory study was performed to evaluate the effect of mix variations on properties of asphalt rubber mixtures. The purpose of this study was to develop an asphalt rubber binder (Figure 2) that had a storage time of up to 8 days and would meet the following criteria: (a) a ball and ring softening point temperature greater than 65°C and (b) a penetrability of 70 to 100/10 mm at 25°C.

The effect of crumb rubber, oil extender, and catalyst content on the properties of asphalt rubber binder are presented in the following sections.

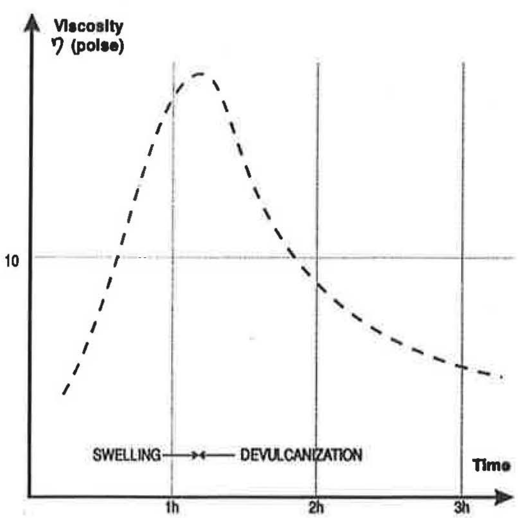

FIGURE 1 Viscosity evolution through rubber digestion.

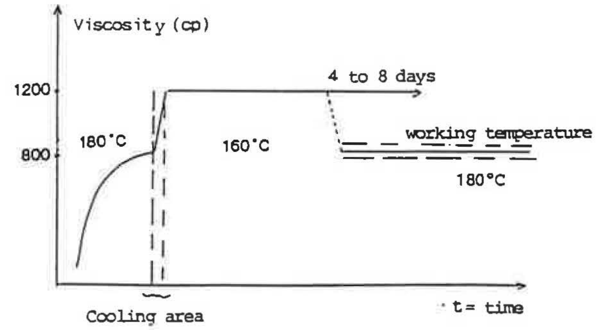

FIGURE 2 Desired viscosity characteristics.

Effect of Crumb Rubber

The effect of three different crumb rubber contents (8 percent, 9 percent and 10 percent rubber) on the viscosity, softening point, resilience, and penetrability of asphalt rubber binder was evaluated. The results are presented in Figures 3, 4, and 5. The results indicate that the optimum properties can be achieved at 10 percent crumb rubber content.

Effect of Oil Extender

The effect of four different content levels of oil extender was evaluated (3 percent, 4 percent, 5 percent, and 6 percent oil extender). The results indicate that an increase in the percentage of oil extender will decrease ring and ball softening point, increase penetrability, increase the capacity for stretching and tension, and reduce resistance. A maximum of 6 percent of oil extender provides optimum asphalt rubber binder properties. The results of this testing are presented in Figure 6.

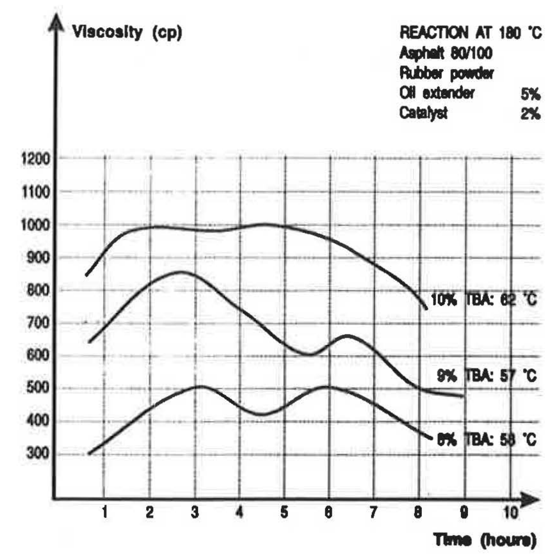

FIGURE 3 Change in viscosity for different rubber percentages.

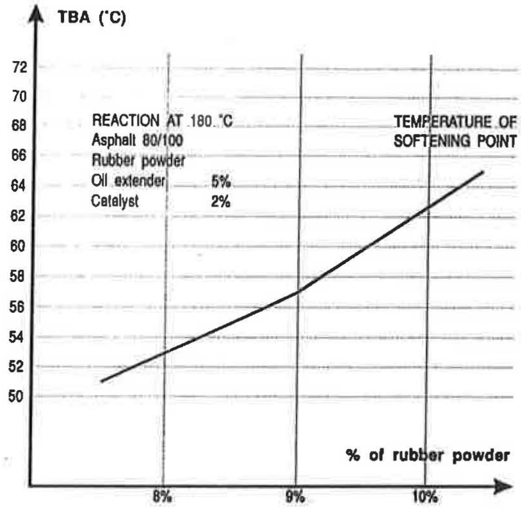

FIGURE 4 Change in ball ring softening point as a function of the percentage of rubber.

Effect of Catalyst

Two levels of catalyst, 2 percent versus 3 percent, were evaluated. The results indicate a maximum of 2½ percent catalyst provides the optimum asphalt rubber binder properties. This catalyst can be selected from ethylenically unsaturated polymers or copolymers that historically have been recommended for incorporation into sulphur-vulcanized bitumen intended for road surfacings or similar products. The results of this testing are presented in Figure 7.

A formulation was developed to provide a storable asphalt rubber binder composition based on the test results previously presented.

Storable Asphalt Rubber Binder	*Composition (percent)*
Asphalt 80/100	81.5
Rubber powder	10.0
Oil extender	6.0
Catalyst	2.5

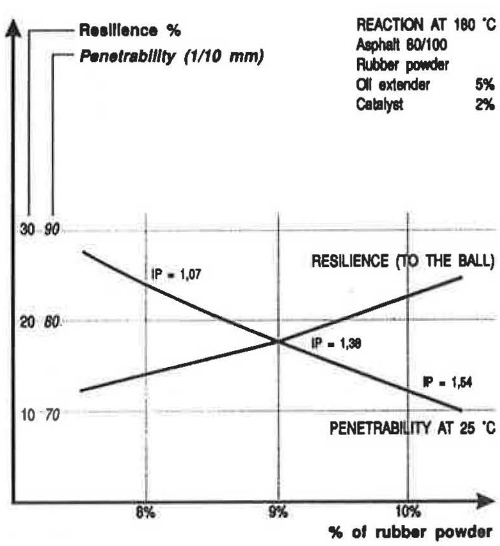

FIGURE 5 Change in other properties as a function of the percentage of rubber.

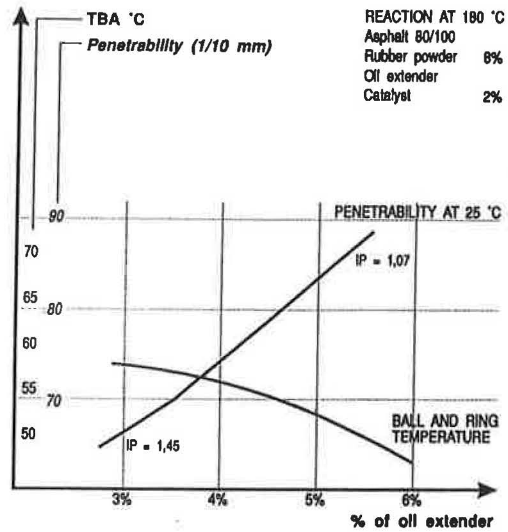

FIGURE 6 Changes in penetrability and ball and ring softening point properties as a function of the percentage of oil extender.

The asphalt rubber binder was produced using the optimized storable asphalt rubber binder formulation. The binder was produced at 180°C (the production process takes about 2 hr), then stored in tanks at 160°C in a hermetically sealed vessel without agitation. Samplings were taken at regular intervals in order to monitor the change in the product. Properties of the asphalt rubber binder after production were as follows:

Ball and ring softening point	65°C
Penetrability in 1/10 mm at 25°C	70
Viscosity (Rheomat)	640 cp at 180°C 1070 cp at 160°C
Stretching under tension to rupture point at −10°C	330 percent

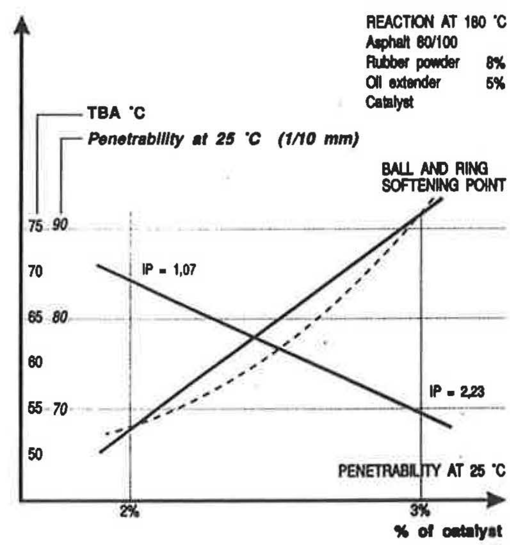

FIGURE 7 Change in penetration and TBA properties as a function of the amount of catalyst.

Results of the evaluation of the properties of the storable asphalt rubber binder after 6 days of storage provided the following results:

Ball and ring softening point	72.5°C
Penetration at 25°C in 1/10 mm	85
IP Pfeiffer	+1.34
Viscosity (Rheomat)	1040 cp at 160°C 1070 cp at 180°C
Rupture point stretching under tension at −10°C	350 percent

Conclusions of the laboratory study show that the formulation developed was consistent with the predetermined specification. After a week of storage at 160°C, there was no noticeable degradation of the asphalt rubber binder.

Advantages of Storable Asphalt Rubber Binder for Industrial Applications

Until development of the storable asphalt rubber binder, it was necessary to prepare the asphalt rubber binder just before use in plant production. Hence, it was mandatory to have a mobile asphalt rubber binder blending unit at the site of the asphalt paving plant. Without storable asphalt rubber binder the following production disadvantages are encountered:

1. Inability to supply high-capacity hot-mix plants with enough asphalt rubber binder to meet their design production rates.
2. If there is a failure, either at the hot-mix plant or in the paving operation, the storage of the asphalt rubber binder at high temperature is impossible (because of the loss of quality).
3. For small projects, it is cost-prohibitive to use the mobile unit considering the cost of mobilization. In most cases, it was impossible to compete with other techniques using, for example, polymer-modified bitumen that was prepared in fixed units and could be stored for several days.

However, with storable asphalt rubber binder, it is possible to prepared in advance the asphalt rubber binder to meet the high production rates of asphalt plants. Moreover, climate conditions, plant operations, or paving-equipment failures no longer have an influence on the production or quality of the asphalt rubber binder.

Advances in Technology of Rubber-Modified Asphalt Concrete (Dry System)

The addition of crumb rubber to replace some of the mineral aggregate in asphalt concrete mixtures was developed in Europe at approximately the same time that the asphalt rubber binder process was gaining notoriety in the United States. The system of adding crumb rubber directly to the mixture, either at the recycle fit opening at a drum plant or with the dry aggregate at the pugmill, is referred to as the dry system of rubber-modified asphalt concrete.

This system, developed in Sweden, was patented in North America and marketed under the trade name PlusRide. This process used relatively large pieces of crumb rubber (1/4 in. minus) produced from used tires. The crumb rubber is then added at the rate of 3 percent of total weight of the mixture. The patented specification requires a unique gap-graded aggregate gradation (*4*).

Production Barriers

In the PlusRide rubber-modified asphalt concrete system, the major components that increase cost are as follows (*5*):

- Specialized aggregate crushing to obtain the unique gap-graded aggregate gradation,
- High mineral filler content (8 to 12 percent),
- Increase in optimum asphalt cement content (7.5 to 9.5 percent),
- Increase in mixing temperature (300 to 350°F discharge temperature), and
- License fee for using the patented process.

Technical Barriers

The technical barriers encountered with the use of the PlusRide system are a combination of a lack of design criteria and nonconventional testing methods (*6*).

Evaluation of Rubber-Modified Asphalt Concrete (TAK System)

A new asphalt rubber system was developed in 1986 by H. Barry Takallou, referred to as the TAK System (*7–9*). This system relates to a process for producing an asphalt concrete composition made up of a coarse crumb rubber, a fine crumb rubber, asphaltic binder, and mineral aggregate. A catalyst to improve the reaction between fine crumb rubber and asphaltic binder, and anti-stripping agents may be added as determined by asphaltic binder and crumb rubber compatibility tests.

This process is characterized by the various constituents of the asphaltic binder and fine crumb rubber, mixed intimately by a physical reaction. This will result in a higher viscosity binder in which the optimum reaction is achieved when the fine crumb rubber particles reach optimum swelling. A pre-reaction or pre-treatment of crumb rubber with a catalyst may be needed to achieve the optimum crumb rubber particle swelling. The coarse crumb rubber will be added as part of the composition to act as an elastic aggregate, to improve elastic properties of asphalt concrete pavement, and to reduce temperature susceptibility.

The aim of this system is to remedy the drawbacks found in other systems. These include the use of specialized mixing equipment, specialized mineral aggregate gradations, and specialized design criteria. The TAK System combines coarse and fine crumb rubber to produce a binder that has asphalt rubber binder quality, and provides superior elastic properties for asphalt concrete pavement. Therefore, there is no need for specialized mixing equipment. In this system the mineral aggregate is constant while the crumb rubber gradation is variable in the composition. The crumb rubber gradation is optimized per each mix design. However, the size of a majority of the crumb rubber should be less than U.S. sieve size

No. 10. Also, the TAK System can be designed with conventional testing equipment and conventional design criteria.

The asphaltic composition of the asphalt binder can be any of a variety of conventionally available materials; this includes, but is not limited to, any polymer-modified asphalt binder, and any modified asphaltic binder material as long as the asphaltic binder and crumb rubber are compatible.

In this system, the rubber content in the composition should not exceed 2 percent for open-graded or dense-graded wearing course, and 3 percent for binder course, by total weight of the mixture.

The crumb rubber used should be processed from whole passenger and semi and truck tires. Heavy equipment tires should not be used. The crumb rubber larger than 16 mesh size should be processed by ambient granulation. The crumb rubber smaller than 16 mesh size may be produced from either granulation or grinding. Uncured or devulcanized rubber is not acceptable. Rubber tire buffings from either recapping or manufacturing processes may not be used as supplement to the crumb rubber. The crumb rubber provided should not be elongated in shape and should be free of contaminants including fiber, metal, and mineral matter.

The use of this system is in the public domain; therefore, there are no license fees required to use it. The system uses a standard dense-graded aggregate so that no unique or gap-graded aggregate gradation requirement is necessary.

Demonstration projects using the TAK System have been constructed by several state departments of transportation. The New York Department of Transportation has adopted and issued design specifications for the incorporation of crumb rubber from whole tire recycling using the TAK System concept.

The Province of Ontario, Canada, has also investigated the use of crumb rubber incorporated into asphalt concrete mixtures. In 1990, The Ministry of Transport constructed two demonstration projects using the rubber-modified asphalt concrete TAK System. These demonstration projects were constructed in an effort to evaluate its constructibility and performance, and to monitor air emissions during production and paving operations.

The two projects were constructed in separate regions of the province without any significant problems. In one project, the mixture was produced at a drum drier-type plant and in the other project a batch plant was used. The rubber-modified hot mix material was laid with a standard paving machine and compacted and rolled with standard equipment. Preliminary results show the rubber-modified sections to be performing as well as the conventional control sections and again, laboratory testing indicates superior performance is to be expected with rubber-modified asphalt concrete.

The air emission testing was performed for both rubber-modified asphalt concrete, TAK System, and conventional asphalt concrete. Results of the air emissions testing, from samples taken at the stack in the production of the mixtures and from personal air monitoring devices worn by the paving crew, indicate that the emissions from rubber-modified asphalt concrete Tak System are virtually identical to those of conventional asphalt concrete.

These demonstration projects also addressed the recyclability of rubber-modified asphalt concrete, TAK System, and stack emission testing was performed when the recycled rubber asphalt pavement was introduced to produce a recycled rubber asphalt concrete mixture. The rubber-modified asphalt concrete material proved to be recyclable.

CONCLUSION

The major barrier to the widespread use of rubber-modified asphalt concrete has been the increase in cost of using the material compared with conventional asphalt concrete. In the wet system, specialized equipment that had to be mobilized with each project led to a high cost for asphalt rubber binder. The mobile equipment was required because the binder had to be used within hours of production. With the development of storable asphalt rubber binder (Flexochape), it can be produced in central terminal locations and shipped like conventional asphalt cement to the production facility for use. This development will lower the cost of asphalt rubber binder, provide uniform and consistent binder qualities, and generally have a positive impact on a more widespread use of the material.

Technological advances in the dry system have also reduced the barriers to its use on a more widespread basis. The major barriers to widespread use were the unique aggregate gradation, high asphalt content, high filler content, high mixing temperature, nonuniform rubber gradation, lack of adequate design criteria, and use of a patented system. These barriers have been addressed with the introduction of the TAK System of rubber-modified asphalt concrete. This system allows the roadway engineer to specify a standard dense-graded aggregate specification using standard mix designs, test procedures, and criteria. TAK System uses conventional mixing procedures, compaction equipment, and quality-control testing procedures. These developments have lowered the production and construction costs of using the material. The use of the TAK System is in the public domain.

Air emission testing of the TAK System was performed in the Province of Ontario. Emissions tests were taken during production at both a drum drier plant and a batch plant for TAK System and conventional asphalt concrete. Air emission test samples were also taken during the paving operation, gathered from personal air-monitoring devices worn by the crew. Analysis of the air samples taken, both in production and at the job site, indicates no difference in air emissions with rubber-modified asphalt concrete compared with conventional asphalt concrete. The recyclability of rubber-modified asphalt concrete, TAK System, was also confirmed in these demonstration projects.

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